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(54) **High frequency switched attenuator.**

(57) In a high-frequency switched attenuator comprising input and output connections (1,2), a signal by-pass path (8), an attentuator network (A), and a relay switch (5) having a first condition in which the input and output connections are interconnected by the by-pass path and a second condition in which the input and output connections are interconnected through the attentuator network, a compensation network (LC) comprising an inductive component (L) and a variable capacitive component (C) is connected between the input and output connections (1,2).

EP 0 208 441 A2

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High-Frequency Switched Attenuator

This invention relates to a high-frequency switched attenuator.

An object of the invention is to provide a switched attenuator for use at high frequencies, for example in a transmission line, for the purpose of introducing selectively, under control of a switch, a predetermined degree of attenuation.

It is known to provide switch-selectable attenuators for use at high frequencies and for connection to coaxial transmission lines. Such attenuators are used, for example, in instrument calibration. One known such attenuator is described in U.S. Patent Specification 4330765 (Patukonis) and consists of a number of attenuator stages carried on a common substrate and controlled by individual relay switches with associated change-over contacts. When the associated relay is in one state an input signal is routed through an associated attenuation network to impart a predetermined degree of attenuation to the signal, while with the relay in its other state the signal by-passes the attenuation network. By selectively energising the relays it is possible to cascade attenuator stages with different attenuation factors to provide a variety of overall attenuation values.

The problem associated with high-frequency attenuators is that of maintaining an accurate predetermined attenuation over a wide frequency range. The switch contacts associated with each attenuation stage define

between them an inherent capacitance which, in the higher attenuation stages, is a significant source of error. The switch capacitance presents a secondary path by-passing the associated attenuator network to an extent which increases as the frequency of the signal increases. The problem is aggravated where there is a difference in the electrical lengths of the primary path through the attenuator network and the secondary path presented by the switch capacitance: a path length difference of only a few millimetres can cause a dip in the frequency response of the attenuator at the upper end of the frequency band for which the attenuator is designed.

In order to compensate for the frequency-dependent switch capacitance effect in switch attenuators it has been proposed to provide a switched attenuator with a path length in the attenuation network which can be adjusted, for example, by selective removal of a conductive track on an insulating substrate. Adjustment of the path length in this way has the disadvantage that it is irreversible. Moreover, the method is capable only of correcting for a steady increase of attenuation with increase in frequency, and is not ideally suited to compensating for a dip in the frequency response.

The present invention aims to provide a high-frequency switched attenuator with a readily adjustable means for compensating for frequency-dependent parasitic effects introduced by the switch.

According to the present invention there is provided a high-frequency switched attenuator comprising input and output connections, a signal by-pass path, an attenuator network, and a relay switch having a first condition in

which the input and output connections are interconnected by the by-pass path and a second condition in which the input and output connections are interconnected through the attenuator network, wherein the attenuator further includes a compensation network connected between the input and output connections and comprising an inductive component and a variable capacitive component.

The attenuator may be embodied with others as a part of a programmable step attenuator unit. The attenuator network is preferably formed on a substrate of dielectric material and is constituted by layers or coatings selectively deposited on the substrate. Similarly, the compensation network may be carried on a substrate of dielectric material. In a preferred embodiment the substrate carrying the compensation network is physically separate and distinct from the susbtrate carrying the attenuation network. This enables different compensation networks to be fitted to and connected electrically to a given attenuator network.

The variable capacitance preferably includes a rotary trimmer capacitor. The capacitance preferably also includes fixed capacitive components formed, for example, by layers deposited on opposite faces of the substrate carrying the compensation network.

The inductive component of the attenuator network may similarly comprise inductive strip elements carried on the substrate of the compensation network. For example, two inductive strip elements may be carried on the same substrate as the capacitance and may connect the latter to the respective input and output connections. In one

embodiment of the invention the variable capacitance may be connected electrically in series with the two inductive strip elements, while in another embodiment the variable capacitance may form part of an earth connection between the two inductive strip elements.

In some practical embodiments of the invention the inductive component of the compensation network may be constituted by the spurious self-inductance of the trimmer capacitor. This may be the case, for example, where the compensation network is associated with an attenuator network having a low attenuation factor.

The switched attenuator of the present invention and its associated compensation network constitutes an attenuator pad or cell which may in turn form a modular component of an a programmable step attenuator unit. Thus, an attenuator unit in accordance with another aspect of the invention may comprise a number of high frequency switched attenuator pads or cells, each individually compensated. This renders the task of fault rectification much simpler and more economical, since individual attenuator pads or cells can be replaced as required, in contrast to known card attenuators in which a number of attenuator cells are carried on a single substrate.

The invention will be further described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a simplified equivalent circuit of a single high-frequency switched attenuator section;

Figure 2 is an equivalent circuit of a high-frequency

switched attenuator according to one embodiment of the present invention;

Figure 3 is a diagrammatic exploded perspective view of a switched attenuator according to the invention, corresponding to the equivalent circuit of Figure 2;

Figures 4, 5 and 6 are respectively a top plan view, a side elevational view and a back view of one form of compensation network for use in a switched attenuator according to the invention;

Figure 7 is an equivalent electrical circuit of the compensation network illustrated in Figures 4, 5 and 6;

Figures 8, 9 and 10 are respectively a top plan view, a side elevational view and a back view of an alternative compensation network for use with a high-frequency switched attenuator according to the invention, and

Figure 11 is an equivalent electrical circuit of the compensation network shown in Figures 8, 10.

In the electrical equivalent circuit of Figure 1 an attenuator network, generally indicated A, is connected to input and output connectors 1, 2 through respective changeover switches 3, 4 associated with a relay 5. The electrical signal path between the switches 3, 4 and the attenuator network is represented by resistive connector elements 6, 7. The relay 5 has a first condition in which the switches 3, 4 (shown by broken lines) connect the input and output connectors 1, 2 to a signal shunt or by-pass path 8 and a second condition in which the switches 3, 4, shown by full lines, connect the input

and output connectors 1, 2 to the attenuator network A.

For the attenuation of high frequencies the leakage capacitance C_S across the relay switch contacts when the switches 3, 4 are in their second condition becomes a major source of error, particularly when the attenuator network A has a high attenuation factor. The leakage capacitance C_S constitutes a secondary path by-passing the attenuator network A.

The problem is aggravated if there is a difference between the electrical length of the primary signal path through the attenuator network A and the secondary path through the leakage capacitance C_S: path differences of only a few millimetres can cause a dip in the frequency response of the attenuator at the top of its frequency band of normal operation.

It is possible to select a critical value for the electrical signal path length through the attenuator to compensate for the effect of the leakage capacitance C_S and to minimise the frequency response error. This critical path length, however, is strongly dependent upon the switch leakage capacitance C_S and is difficult and expensive to achieve in practice, particularly if use has to be made of variable length transmission line sections.

An alternative solution proposed in, for example, U.S. Patent Specification 4330765 is to connect an inductor L_g in the earth connection of the attenuator network A, as shown diagrammatically in Figure 1. This has the effect of lifting the frequency response at the upper end of the range, compensating for the increase in attenuation with increasing frequency caused by the leakage

capacitance C_S.

For a typical leakage capacitance C_S of 0.1 picoFarad the compensating inductor Lg would be of the order of 0.25 nanoHenry. The inductor Lg would normally be formed by a short conductive track on an insulating substrate, the inductance value being adjusted by trimming the cross-section of the track. This method of compensation is specific to a particular critical path length such that the dip in the frequency response is placed above the upper end of the working frequency range of the attenuator.

The present invention provides a compensation network, identified LC in Figure 1, which is connected across the attenuator network A.

The equivalent electrical circuit shown in Figure 1 can be analysed using a computer program. The relay 5 can be represented electrically as an ideal switch of zero electrical length. The connector elements 6, 7 are each taken as equivalent to a 50 ohm transmission line, and the attenuator circuit A is assumed to be a perfect 30dB attenuator section with a 50 ohm terminating impedance. Using this model the different methods of compensation of the attenuator can be compared. Four different cases are considered, the electrical length of the equivalent resistive connector elements 6, 7 being identified "T" in each case:

(i) Uncompensated

Characteristics	Attenuation:
T = 7 mm	-58dB at 2.2 GHz
Lg = 0	-47DB at 2 GHz

(ii) Compensation by adjustment of electrical length T to optimum

Characteristics	Attenuation
T = 2.53 mm	
Lg = 0	-30.03dB at 1.2 GHz
LC = open circuit	-29.975dB at 2 GHz

(iii) Ground Inductance Compensation, Lg adjusted.

T = 7 mm	
Lg = 0.223nH	-29.62dB at 1.2 GHz
LC = open circuit	-30.34dB at 2 GHz

(iv) LC Compensation, L and C adjusted to optimum

T = 7 mm	
Lg = 0	-30.007dB at 1.2 GHz
LC: L = 22.82nH	-29.992dB at 2 GHz
C = 0.069pF	

The values of L and C in the compensation network would in practice be about 40nH and 0.05pF respectively for a 30dB attenuator section, and about 5nH or less and 0.3pF respectively for a 20dB attenuator section. By arranging for the capacitive component C to be adjustable it is possible to correct for errors in the magnitude of the inductive component, which does not, therefore, have to be of high precision.

By providing an LC compensation network, preferably with an adjustable capacitive component, it is therefore possible to achieve effective compensation over the working frequency range of the attenuator at relatively

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low cost compared with the alternatives given in examples (ii) and (iii) above.

A practical embodiment of a high—frequency attenuator according to the invention is illustrated in Figure 3, and its electrical equivalent circuit in Figure 2. The attenuator forms a single section or pad of a multiple-section step attenuator unit. The attenuator network A is formed by resistive elements 9 deposited on a substrate 10 of high dielectric constant, preferably alumina.

The input and output connectors 1 and 2 comprise respective microstrip lines deposited on the substrate 10 and connectable to respective microstrip lines constituting the connector elements 6 and 7 through the respective relay switches 3 and 4 when the associated relay 5 is in its second condition. The relay 5 is attached to the substrate 10 on the side opposite the connectors 1, 2, 6 and 7. The by-pass path 8 to which the switches 3 and 4 are connected in the first condition of the relay 5 consists of a further microstrip line section deposited on the substrate 10.

As stated previously, the input and output signal path lengths of the attenuator must be kept as short as possible. By using an LC compensation network the path length can be longer (typically 14 mm for a 30dB attenuator section) than that necessary (e.g. 5.06mm) if the critical length compensation technique is used.

The LC compensation network comprises inductive and capacitive components carried on a substrate 11, also of alumina, separate from and mounted on the substrate 10.

The compensation network is connected across the attenuator network by connector pins 12, 13 which make contact with the connector elements 6, 7 respectively.

In the embodiment of Figures 4-7 the LC compensation network comprises two thin microstrip tracks L_1, L_2 on the underside of the substrate 11 (Figure 6) connected in series with respective fixed parallel plate capacitive elements C_1, C_2 formed by respective pairs of coatings 14, 15 and 16, 17 deposited on the opposite faces of the substrate 11. A variable capacitor C_3 interconnects the two fixed capacitances C_1, C_2. The variable capacitor C_3 comprises a rotary trimmer capacitor carried on the opposite face of the substrate 11 from the inductive tracks L_1, L_2 and connected electrically to the conductive coatings 14, 16 of the fixed capacitances. The trimmer capacitor C_3 allows adjustment of the capacitive component over a small tuning range. In this example the inductive component L_1, L_2 of the compensation network is nominally about 40nH while the capacitive component C_1, C_2, C_3, is nominally 0.05pF.

For adjustment of the trimmer capacitor C_3 over a wider range the compensation network of Figures 8-11 may be used in which the variable capacitor C_3 forms part of a ground connection between the two fixed capacitances C_1, C_2. The trimmer capacitor C_3 introduces a variable capacitance between the two fixed capacitances C_1; C_2, and the addition of the capacitance to ground is offset by reducing the series inductive components L_1, L_2.

The compensation networks shown in Figures 4 to 7 and 8-11 are intended for use with attenuator sections of about 30dB attenuation. For smaller attenuation steps,

of about 20dB value, a trimmer capacitor can be used alone with no additional inductive components, because the required inductance is of the same order as the trimmer capacitor's spurious self-inductance.

The chief advantages of the compensated high-frequency attenuator of the present invention may be summarised as follows:

(a) The introduction of the LC compensation network allows greater latitude in the design of the signal path length in the attenuator, without the need to adhere to the critical path length for the connectors to the attenuator network. The resistor network forming the attenuator can thus be larger and further away from the relay switch assembly than is possible under the critical path length criterion.

(b) As a result of (a) the power handling ability of the attenuator network is enhanced, since the resistors making up the network can be physically large and close to a heat sink when the attenuator section is assembled into a multiple step unit.

(c) The mechanical accuracy required in the attenuator circuit components is less stringent than that required in an equivalent attenuator designed according to the critical path length criterion.

(d) Despite the increased path length the frequency response accuracy is better than that of the equivalent critical path length attenuator.

(e) The adjustability of the compensation by means of an adjustable trimmer capacitor is convenient and

reversible, as compared with the use of a variable inductor.

(f) The relay itself can be replaced and the compensation network re-adjusted without making any irreversible adjustments or changes.

CLAIMS

1. A high-frequency switched attenuator comprising input and output connections (1,2), a signal by-pass path (8), an attenuator network (A), and a relay switch (5) having a first condition in which the input and output connections (1,2) are interconnected by the by-pass path (8) and a second condition in which the input and output connections (1,2) are interconnected through the attenuator network (A), characterised in that the attenuator further includes a compensation network (LC) connected between the input and output connections (1,2) and comprising an inductive component (L) and a variable capacitive component (C).

2. A switched attenuator according to Claim 1, characterised in that the compensation network (LC) is carried on a substrate (11) of dielectric material.

3. A switched attenuator according to Claim 1 or Claim 2, characterised in that the attenuator network (A) is formed on a substrate (10) of dielectric material.

4. A switched attenuator according to Claim 2 and Claim 3, characterised in that the substrate (11) carrying the compensation network (LC) is physically separate and distinct from the substrate (10) carrying the attenuator network (A).

5. A switched attenuator according to any one of the preceding claims, characterised in that the variable capacitance (C) includes a rotary trimmer capacitor

(C_3).

6. A switched attenuator according to Claim 5, characterised in that the inductive component (L) of the compensation network is constituted by the spurious self-inductance of the trimmer capacitor (C_3).

7. A switched attenuator according to any one of Claims 1 to 5, characterised in that the inductive component comprises two inductive strip elements (L_1, L_2) carried on the same substrate (11) as the capacitance (C_1, C_2, C_3) and connecting the latter to the respective input and output connections.

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FIG 1

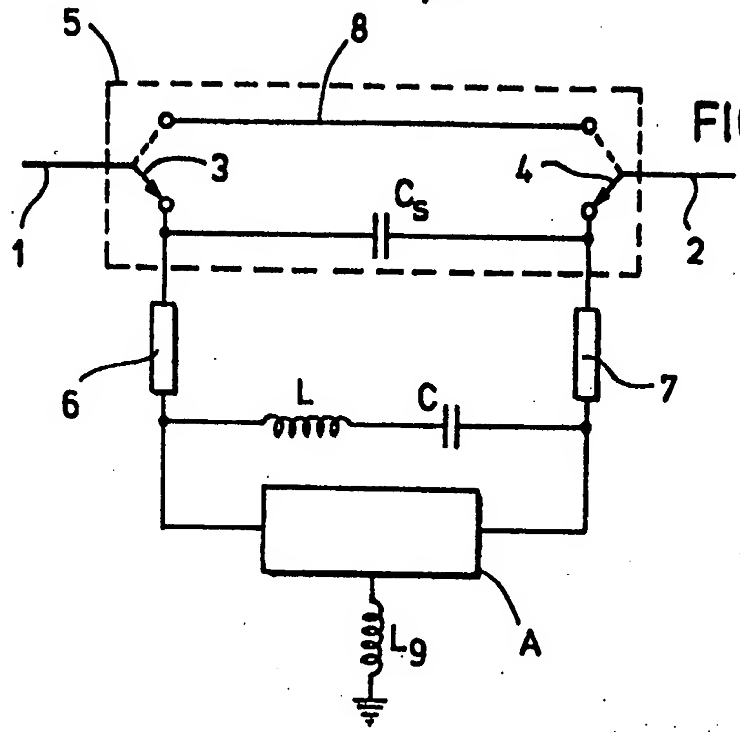

FIG 2

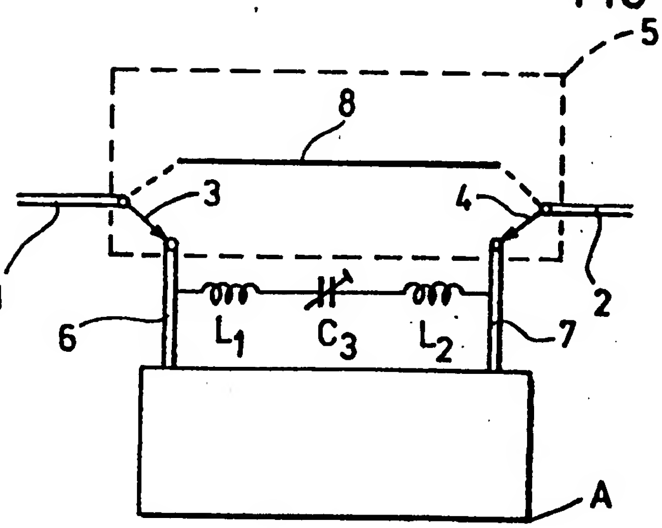

FIG 3

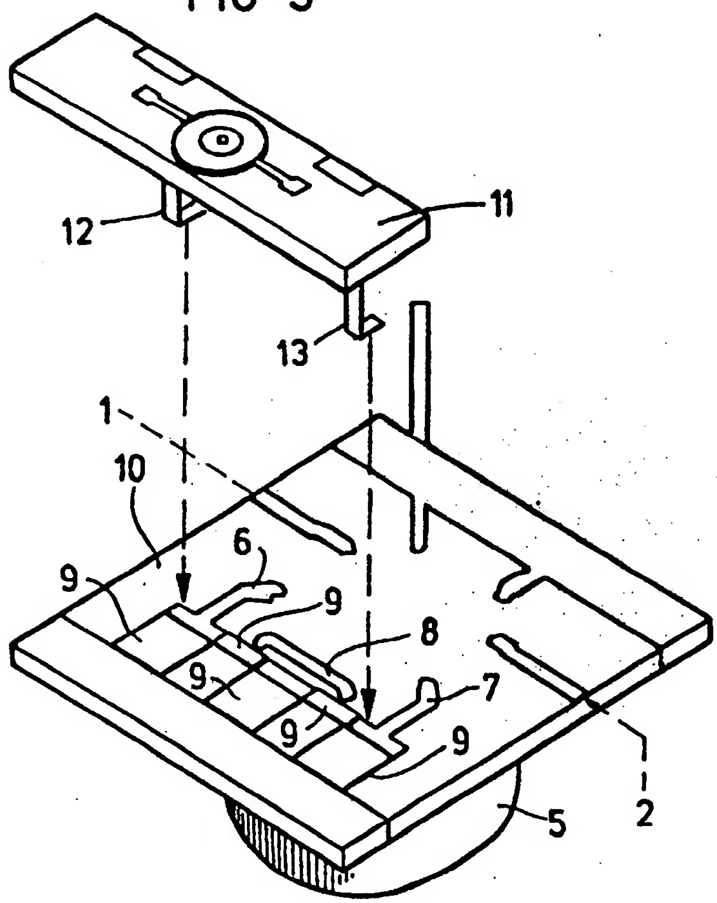

FIG 4

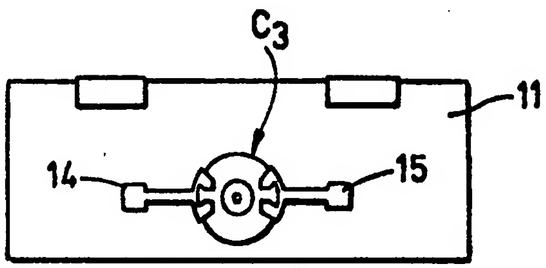

FIG 5

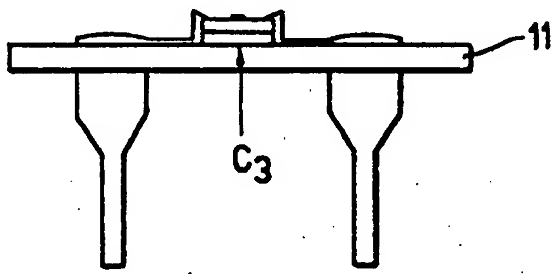

FIG 6

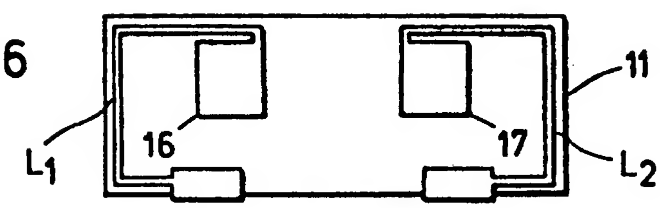

FIG 7

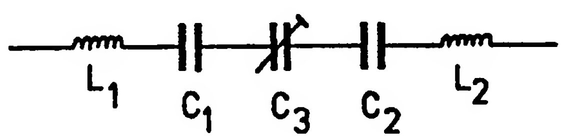

FIG 8

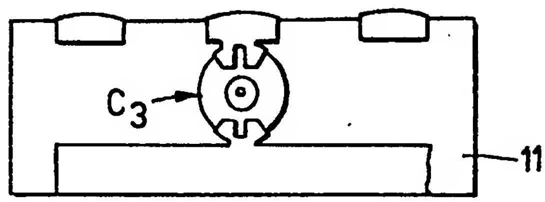

FIG 9

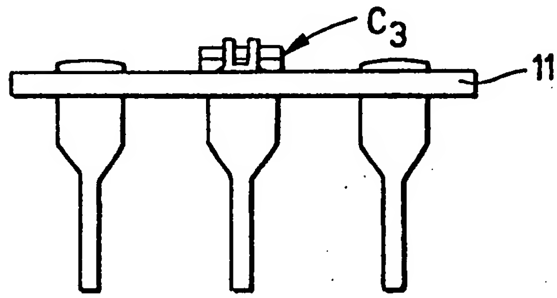

FIG 10

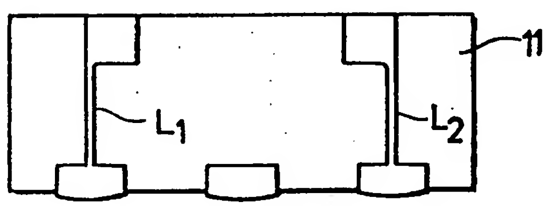

FIG 11